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Phenomenological Survey of a Minimal Superstring Standard Model ^a

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We discuss a heterotic-string solution in which the observable sector effective field theory just below the string scale reduces to that of the MSSM, with the standard observable gauge group being just $SU(3)_C \times SU(2)_L \times U(1)_Y$ and the $SU(3)_C \times SU(2)_L \times U(1)_Y$ -charged spectrum of the observable sector consisting solely of the MSSM spectrum. Associated with this model is a set of distinct flat directions of vacuum expectation values (VEVs) of fields that all produce solely the MSSM spectrum. Some of these directions only involve VEVs of non-Abelian singlet fields while others also contain VEVs of non-Abelian charged fields.

1 Flat Directions in Three-Generation Heterotic-String Models

Over the past decade the free fermionic formulation¹ of the heterotic string has been utilized to derive the most realistic^{2,3} string models to date. In some of these models the observable sector gauge group directly below the string scale is a Grand Unified Theory while in others it is the (MS)SM gauge group, $SU(3)_C \times SU(2)_L \times U(1)_Y$, joined by a few extra $U(1)$ symmetries. In chiral three generation models of the latter class, one of the additional Abelian gauge groups is inevitably anomalous. That is, the trace of the $U(1)_A$ charge, $\text{Tr } Q^{(A)}$, generates a Fayet-Iliopoulos (FI) term,

$$\epsilon \equiv \frac{g_s^2 M_P^2}{192\pi^2} \text{Tr } Q^{(A)}. \quad (1)$$

The FI term breaks supersymmetry near the Planck scale, and destabilizes the string vacuum. Supersymmetry is restored and the vacuum is stabilized if

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there exists a direction, $\phi = \sum_i \alpha_i \phi_i$, in the scalar potential which is F -flat and also D -flat with respect to the non-anomalous gauge symmetries and in which $\sum_i Q_i^A |\alpha_i|^2$ and ϵ are of opposite sign. If such a direction exists it will acquire a vacuum expectation value (VEV) cancelling the anomalous D -term, restoring supersymmetry and stabilizing the string vacuum. Since the fields corresponding to such a flat direction typically also carry charges for the non-anomalous D -terms, a non-trivial set of constraints on the possible choices of VEVs is imposed:

$$\langle D_A \rangle = \sum_m Q_m^{(A)} |\langle \varphi_m \rangle|^2 + \epsilon = 0 , \quad (2)$$

$$\langle D_i \rangle = \sum_m Q_m^{(i)} |\langle \varphi_m \rangle|^2 = 0 , \quad (3)$$

$$\langle D_a^\alpha \rangle = \sum_m \langle \varphi_m^\dagger T_a^\alpha \varphi_m \rangle = 0 , \quad (4)$$

with T_a^α a matrix generator of the non-Abelian gauge group g_α for the representation φ_m . These scalar VEVs will in general break some, or all, of the additional symmetries spontaneously.

Additionally one must insure that the supersymmetric vacuum is also F -flat. Each superfield Φ_m (containing a scalar field φ_m and chiral spin- $\frac{1}{2}$ superpartner ψ_m) that appears in the superpotential imposes further constraints on the scalar VEVs. F -flatness will be broken (thereby destroying spacetime supersymmetry) at the scale of the VEVs unless,

$$\langle F_m \rangle \equiv \langle \frac{\partial W}{\partial \Phi_m} \rangle = 0; \quad \langle W \rangle = 0, \quad (5)$$

where W is the superpotential which contains cubic level and higher order non-renormalizable terms. The higher order terms have the generic form

$$\langle \Phi_1^f \Phi_2^f \Phi_3^b \cdots \Phi_N^b \rangle .$$

Some of the fields appearing in the non-renormalizable terms will in general acquire a non-vanishing VEV by the anomalous $U(1)$ cancellation mechanism. Thus, in this process some of the non-renormalizable terms induce effective renormalizable operators in the effective low energy field theory wherein either all fields or all fields but one are replaced with VEVs. One must insure that such terms do not violate supersymmetry at an unacceptable level.

2 A Minimal Superstring Standard Model

In addition to possessing an anomalous $U(1)_A$ symmetry, chiral three generation $SU(3)_C \times SU(2)_L \times U(1)_Y \times \prod_i U(1)_i$ models generically contain numerous non-MSSM $SU(3)_C \times SU(2)_L \times U(1)_Y$ -charged states, some of which only carry MSSM $\times \prod_i U(1)_i$ charges and others of which also carry hidden sector (non)-Abelian charges. Recently, we showed that in some of these models it is actually possible to decouple all such non-MSSM states from the low energy effective field theory. For example, in the “FNY” model first presented in Ref. 3, we discovered there are several flat directions^{4,5} for which almost all MSSM-charged exotics receive FI masses (typically of the scale 5×10^{16} GeV to 1×10^{17} GeV) while the remaining MSSM-charged exotics (usually composed of simply a $SU(3)_C$ triplet/anti-triplet pair) acquire masses slightly suppressed below the FI scale by a factor of $\mathcal{O}(\frac{1}{10}$ to $\frac{1}{100})$. Some of our flat directions accomplishing this feat contain only VEVs of non-Abelian singlet fields^{5,6} while others of ours also contain VEVs of non-Abelian charged fields^{7,8}. Along these directions, exactly three generations of $(Q_i, u_i^c, d_i^c, L_i, e_i^c, N_i^c)$ fields and a pair of electroweak Higgs, h_u and h_d , are the only MSSM-charged fields that remain massless significantly below the FI scale. The non-MSSM-charged singlet fields and hidden sector non-Abelian fields that also remain massless below the FI scale vary with the flat direction chosen.

The complete massless spectrums produced, respectively, by four singlet flat directions were presented in Ref. 6. Detailed analysis of the associated three generation mass textures was also performed therein. The leading mass terms were found to be $Q_1 u_1^c \bar{h}_1$ and $Q_3 d_3^c \bar{h}_3$ for all four directions. The non-Abelian directions considered in Ref. 7 produced similar results. This presented a phenomenological difficulty for our first few MSSM-producing flat directions by implying that the left-handed component of the top and bottom quarks live in different multiplets. A more detailed study of the mass textures possible from non-Abelian flat directions is underway and will be presented in Ref. 9.

3 Phenomenological Implications

A string-derived three generation MSSM low energy effective field theory resulting from the decoupling of all MSSM-charged exotics via an anomaly-cancelling flat direction possesses some unique phenomenological characteristics (independent of the viability of the associated MSSM mass matrices). For instance, we found that at least one U_i combination usually remains unbroken by a given flat direction. Generally the surviving extra Abelian symmetries could not have been embedded in $SO(10)$ or E_6 GUTs⁸. Relatedly, a common feature in the surviving U_i combinations is a flavor non-universality. Thus, the

distinctive collider signatures of a Z' arising from one such symmetry will be a non-universality in the production of the different generations. An additional Z' of this type has also been suggested as playing a role in suppressing proton decay in supersymmetric extensions of the Standard Model⁰.

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